Maximum Containership Size Estimation for Latin American Terminals using System Dynamic Simulation Modeling

Rebeca Cáceres, Héctor Mendoza, Lynn Downer, Guimara Tuñón
International Transportation and Logistics Research Center
International Maritime University of Panama, Panama City, Panama.

Israel Castillo
Erasmus University, the Netherlands
Panamá City, Panamá

Abstract

In spite of the recent economic recession of the economies of the West, the container flows and containership average size have experienced continuous growth. New orders for ever greater ships (Post-Panamax vessels with capacities beyond 8000 TEUs) have continued. In such a scenario the decisions made by the different stakeholders in the container trade business (liners, terminal operators, port authorities) regarding infrastructure are of critical importance for this sector. In order to provide an accurate decision making tool, a System Dynamics simulation-model is used. Quantitative methods will be used to validate the results of the study. This model will be developed using data of container flows and port calls obtained from a specific Latin-American terminal in order to model the system. This paper provides the conceptual model prior to the operative simulation in Anylogic ™, still in development at this moment. For this, we take into account the sea trade evolution and assumptions of the expanded Panama Canal found in up-to-date forecasts. Variables consider the influence of the current network configurations. We expect the model to prove useful as a tool for terminal operators and port authorities in charge of the infrastructure/superstructure-related decisions throughout the region.

Keywords
System dynamics, simulation, shipping, maritime trade, Panama Canal.

1. Introduction

Maritime trade is one of the major drivers for globalization along with telecommunications, trade liberalization and international standardization. In the last years international trade, has had a faster growth rate than the world’s GDP. The rationale behind the increase in international trade is the development of international supply chains, and in consequence the need to move components and finished goods across the globe, in response to regional and global demand.

The opening of new markets and economy liberalization in most of the developing world has encouraged more investors to build factories and assembly plants in developing countries where costs are lower and regulations are less burdensome. This chain of events has led to a competition not between enterprises but between supply chains and between countries. The patterns that have enabled this increase in International trade were depicted already by Stopford in Maritime economics [1], where he describes how globalization and the consequent decrease in transportation costs has allowed the advent of global supply chains where raw materials and products flow almost freely around the world, making the vision of David Ricardo a reality.

Nowadays, in all major shipping routes, there has been a noticeable increase in the average size of the containerships serving these routes. Such an increase seems to be relentless in spite of the economic conditions and the disappearance of the growth rates experienced during the period 2001-2007.

Such transformation is shown in the Figure 1 that covers the period 1970-2012. In this figure, the evolution of the largest available containerships can be appreciated.
Figure 1: The Largest Available Containership, 1970-2012 (in TEUs). Source: Rodrigue 2013.

1.1. Maritime Trade Trends

World Economy - current developments 2011-2013

The world economy since the second half of 2011 has been showing signs of slowdown after the vigorous recovery of 2010. The weak economic growth in the developed countries so far is the major driver of this situation. The reasons for this phenomenon can be traced to the following factors: Eurozone Crisis, U.S. sluggish growth, Japan weak growth and renewed recession. The year 2012 ended with a small positive growth of 2.2% essentially due to the positive growth of emerging and developing economies as well as the uptick of the American Economy noticeable in higher than expected sales at the end of the year. Forecasts of growth for 2013 are expected to be similar than 2012 [2].

Figure 2: Global GDP Growth, Source: IMF staff estimates.

In the United Nations World Economic Situation and Prospects 2013 three scenarios are considered for the period 2013-2014 namely the “policy scenario” the “Baseline” scenario and the “Downside scenario”. These scenarios are discussed at length within this aforementioned report. Despite the fact that the growth of developing and emerging markets is expected to continue to raise at a small but positive trend, the overall growth of the economy will still be fraught with risks and is not expected to recover the pace it held in 2010, let alone the growth rates observed in the last decade prior to the Financial crisis. The main risks identified by the International Monetary Fund as well as the United Nations are mainly: (1) The critical situation in the European Union (EU) with sovereign debt crisis spilling over other sectors of the economy and the start of recession in several member states (IMF 2013). (2) Uncertainty
about the measures to prevent a “fiscal cliff” has in effect weakened the confidence in the private sector (3) If the situation worsens in the advanced economies, it will not be long before the deleterious effects of this situation are felt in the developing and emerging markets due to the expected decline in the demand for commodities as well as other categories of export products from the developing and emerging markets.


**World Trade**

By the end of 2012, in spite of the weak rebound at the fourth quarter of 2012, the trade volume for advanced economies as well as for the developing and emerging markets, showed signs of decrease. At the beginning of the year, at the first and second quarter exports from developing and emerging markets were on the rise however as the year progressed Eurozone crisis as well as the sluggish growth rates reported from U.S. and Japan, as well as China drove imports from developing nations down [2].

**Regional economic situation**

Latin America has been reporting higher than average growth rates during the last decade (except for 2009) due to favorable market conditions for commodity exports as well as a positive consumption growth in the first world for products originated from this region. According to the International Monetary Fund, economic growth underwent a mild slowdown in the first half of 2012. The performance of the area varied widely per region. South America is more reliant in the commodity sector and has a more diversified trade than Central America or Mexico that are reliant in U.S. trade patterns. In the transpacific trade, South America exports show a reliance on commodity intensive trade (raw materials), being the sub-region’s leading supplier of products for China and developing countries of Asia. For China, up to a 93% of the imports from Latin America come from the South American region. In contrast most goods exported by China to the Latin America region are manufactures not based on natural resources, which in the last years have raised worries in the domestic manufacturer firms in Latin America regarding the growing gap and negative balance trade for these types of goods. Main manufactured goods exported by China to the Latin America countries are textiles, clothing and footwear; rubber and plastic; metal and metal products; machinery and equipment; and automobiles and auto parts. The changes that have taken place in the patterns of the Latin American trade can be better described in the figure 4, where a comparison between the decade of the 90s and the first decade of the 21st century shows a shift in the growth rate of trade per regions.

2. **Containership size evolution**

Containerization of liner services was one of the greatest commercial innovations of the twentieth century [4]. High levels of confidence in the maritime industry are noticeable in terms of new orders being made as well as fleet deployment since early nineties to 2008.
Even though, a reduction in the order books was experienced in the period 2008-2009, a relatively high amount of capacity is still in the order books and new orders are still being made, despite the critical impact from an unbalanced business and shipping cycle. Nevertheless, even suffering the effects of different crisis in the last years, the evolution of containership fleet has had a clear positive trend, as shown in the following chart (in red, right side is graphed the number of ships) [5]. By the end of 2011, the fleet of containerships represented 12.9% of the world fleet and 27 times more in monetary value of goods transported. The forecasts of 2013 and 2014 are developed considering current trends in fleet operation, as well as new orders and demolitions as per 2011.

2.1. Problem of the Optimum Ship Size
The problem of the optimum vehicle size is not something new as can be seen in the literature included in this paper. Since the mid-sixties, correlation between the ship size and the turnaround time was found, when Studer (1966) [6] discovered that the bigger ships, in the case of grain bulk shipments, reported cheaper prices per metric ton the bigger the ship, however the time spent in the port in loading and unloading activities oftentimes negated the economies of scale reported at sea with bigger ships. The variables taken into account during his examination of the more than 1300 grain bulk ship records for the port of Vancouver showed a positive correlation between the shipping costs and the time spent at port (turnaround time). It must be noted that this research was not focused on finding the optimal size for a vehicle/vessel. It was Kendall [7], who tried in his work “A theory of Optimum Ship Size” to develop a theory able to explain the different variables that determine the optimum ship size, applicable to different commodities whether the service is of liners or tramp ships, with predictive value. His definition of the
optimal size of the ship is likely to be the first of his type in the maritime trade, a definition for optimal size which states: “The optimum size of ship for a particular route will be that which minimizes the total transport costs”. His work was applied to the iron ore trade between the U.S. gulf and the Netherlands and Wales and Netherlands, however the author expects the theory to remain valid for different routes and commodities. The factors taken into consideration within his work were only for the supply side of the optimal size problem namely Ship costs (capital charges, running costs), handling costs (total handling cost of handling equipment, percentage rate of return expected on the capital cost, total annual tonnage to be handled, running cost per ton;) and storage costs (total storage cost/ton, total annual tonnage to be handled from a single ship, value of product/ton, percentage rate of return expected on the capital invested in the product during storage, cost/square yard /year, N° of square yard for one year, running cost per ton (not included under the handling costs previously).

On the other hand, studies trying to predict the ship size for specific regions have already taken place, Kee, 2006 [8] tried to determine the optimum ship size for the South East Asia routes, using quantitative as well as qualitative methods taking into consideration factors such as Speed of vessel, voyage distance, port time, total steaming days, total port allowance, total round voyage, charter rate, fuel charges, port expenses, turn around voyage capacity. The Economic Commission for Latin America and the Caribbean in 2012 was the first example of forecasts applied to a specific region for containership sizes, namely South American East and West coast and were the first to take into account amongst the factors of the containership size, the transshipment, due to the importance of the hub and spoke configuration for the region. Based on the relationships discovered and extensive analysis, ships greater or equal than 13000 TEUs are to be expected for South America in the period 2017-2020, for the west coast, for the east coast of South America, such development might start to happen earlier, in the period 2016-2020.

2.2. Drivers and factors behind the containership optimum size
The problem of the optimum ship size has been mentioned numerous times in the existent literature even before the 90s. The approaches used to determine the optimum size for a ship were through the use of analytical models that were based on certain assumptions and even resorted to generalizations in order to fill the gaps on the data due to its scarcity (Thornburn, 1960).

The problem of the size for a containership was treated formally by first time in the work of Jansson and Shneerson, [9]which defines the optimal containership size as “Optimal ship for a route is defined as the ship that carries cargo of a given composition at the lowest total cost for the ship-owner per cargo ton”.

The factors that affect a containership optimum size for a determined route can be put in two categories [9]: costs at sea and costs at port. These categories include ([9], [10], [11], [1], [12], [13]):

- Trade volume at the selected route
- Economies of scale that can be achieved (Enough economies of scale benefits must be reaped in order to offset the diseconomies of scale at port handling costs and logistic costs).
- Distances to be covered.
- Commercial environment
- The handling time in port,
- The cargo volumes on specific routes and
- Draught restrictions in harbours.
- Port superstructure

From these factors, the most important ones are the trade volume at the selected route, economies of scale, the commercial environment (quantity versus flexibility in deliveries) as well as distances and port productivity are the most important factors taken into consideration for the optimum containership size. These main factors are briefly described above:

**Trade Volume**
In order for a containership, classified as mega-container ships (>12000 TEUs), to reap the benefits of the economies of scale savings, the ship must be fully utilized [8]. This is due to the diminishing returns obtained in containerships whose sizes are beyond 6000 TEU [1]. Trade volume is such an important factor that it trumps other important factors like distance and port superstructure and draught limitations.

**Distance**
The longer the route, the greater the importance of the economies of scale in the operation and smaller the impact of the diseconomies of scale and vice versa, the benefits reaped from economies of scale decline as routes length is shortened (Culline and Khanna 1999).

**Economies of scale**

“When long-run average total cost declines as output increases, there are said to be economies of scale.” (Mankiw 2003) In Shipping, economies of scale are said to be achieved when unit cost (DWT or TEUs) decreases as ship size increases (Haralambides 2006). According to previous researchers, the economies of scale achieved by containerships in sizes beyond the Panamax Standard are greatly offset by the diseconomies of scale and the savings are very few in terms of cost reduction per unit (DWT or TEUs). However in the last years these diseconomies of scale as a result of an increase in container handling and logistic costs at the port have been on the wane as a result of the increase in port productivity and multimodality.

**Limitations to the growth in the containership size**

According to the literature the main limitations to the containership size are [1]:

- Technical limitations: Technical and cost related limitations to double engine super post panamax ships, harbour limitations (draught, berth length, etc.).
- Logistic Limitations: congestions in inland terminals, lack of infrastructure necessary in order to haul the containers from the port to its destinations, container yard operations.
- Economic limitations: Limits to the economies of scale, world trade situation.

3. **Cascading Effect**

The deployment of these Ultra Large Container ships (ULCS) in the Asia-Europe trade represents an upgrade of the services located in this lane. This upgrade implies that a new building will replace a smaller vessel previously working in the trade lane. The following figure shows how the participation of vessels in between 3000 and 8000 TEU has decreased in the Asia-Europe trade as a result of the deployment of ULCS. The replaced vessel will be displaced or “cascaded” towards other areas of the world. Figure 6 shows the way that vessels displaced outside the Asia-Europe trade have been redeployed in smaller trades, in this case, the North South trades. This is called the “Cascading effect.” While the reason behind the deployment of the ULCS in Asia-Europe is to reduce unit costs through economies of scale, the reason behind the deployment of cascaded vessels to other smaller trades may not consider the reduction of unit costs as well. The present study shows that economies of scale only reduce unit costs at equal utilization levels. Therefore, the redeployment of cascaded vessels in the range of 5000 to 9000 TEUs towards the transpacific, Asia-Med, and North South trade may aim to utilize the vessel regardless of its load factor. If the cascading effect results in the redeployment of a large vessel into a small service where load factors remain at low levels, the net effect can be an increase in cost per TEU. Therefore, carriers will attempt to minimize increases in cost per TEU by cascading large vessels as much as possible in larger trades.

![Cascading Effect](image)

Figure 6. Ship size ranges and Participation percentage on Trade Lanes. Source: Clarksons Research Services 2012 - 2013 [14].
4. System Dynamics:
System dynamics is a computer-aided approach to high leverage policy analysis and design over time [15]. This approach provides a method for developing and testing mathematical models and computer simulation of nonlinear dynamic systems. Not only have found favorable results while applying it to economic and social systems, but also to urban and ecological systems, among others. This method allows the understanding of complexity, the design of better policies and guide for effective change [16]. Based on the modeling of the system as a causally closed structure defining its own behavior (where modeled agents acquire active participation based on well-established structures); discovering system’s feedback loops, balancing or reinforcing parameters and, identifying stocks and flows affecting it. In example a dominated negative feedback loop process may derive into policy resistance, defined by Thomas Moore in 1516, as the policy changes that do not alter the desired state of negative loops.

![Figure 7. Complex systems characteristics. Source: [16].](image)

Seaborne trade is directly influence by driving forces that add some uncertainty when making decisions. When studying complex and dynamic systems, such as in the maritime industry, different methods can arise. Particularly, economic systems have been intensively modeled through statistical analysis and deep economic theory insights. In spite of acceptable performance of some of these techniques, an issue rises; how to take into account dynamic response of agents to shifts in policy and external shocks as uses to happen in economic systems?. [17] discussed “Lucas critique (1989)”, which sustains that parameters of econometric models are subjected to cross equation restrictions from optimally chosen endogenous variables. In his work, Dikos develops a System-Dynamics modeling approach for the tanker freight industry applied to a case study company, Navier Lines. The model is based on the estimation of time charter rates, considering as endogenous parameters the average of merchant fleet and as exogenous variable the demand. More than generating an accurate forecast tool for system dynamic approaches in the tramp shipping market for tankers, they deployed an easy-to-use and understandable tool for managers to allow for a holistic perspective of their problem (Fig. 7).

At the same time that quantitative and qualitative parameters can be taken both into consideration, a System Dynamic model at a high abstraction level can seek for a macro or strategic perspective. In contrast a microanalysis can generate more details at an operational level. Furthermore, it allows to level aggregation and it has the ability to learn and transmit acquired behaviors. Authors with the most advanced researches applying System Dynamics in the maritime industry have expressed the need for further research in this area stating system dynamics seems like an intuitive decision-support device” Dikos et. al, 2006, and should exploit the highly cyclical container industry.” [18]

5. Containership Size evolution dynamic model
Modeling Approach
In order to adequately attempt to model the interrelationships and factors that drive the containership size evolution and the cascading effect phenomenon, very few previous authors have attempted simulation as could be seen from the Literature review. The reasons for this elude the author at this moment. Analytical methods have been the most common method used so far, however when the complexity [15] reaches a certain point, analytical solutions are not the best suited to provide an answer to a problem in which multiple variables, interrelationships and as is in this case feedback loops influence the outcome. Currently in dynamic simulation there are 3 main simulation paradigms [19] which can be: System Dynamics, Discrete Event Simulation and Agent Based simulation. System Dynamics was chosen due to its high levels of abstraction and capabilities to simulate and accurately represent aggregate units and feedback loops.

5.1. Conceptual Model
Currently the largest containership size has a capacity of 18,000 TEU (the triple-E from Maersk) released in 2013 for the Asia-Europe Route. With 398 meters long and 58 meters breadth is the largest ship in existence, less than 2000 TEUs below the capacity of the “mythical” Malacca Max described by Wijlnost [20] in his study. However this containership size growth still has its limits, namely the economies of scale advantage that the ship-owner can get from such a large ship as well as the availability of terminals able to accommodate the ship and provide the service fast enough in order to ensure the costs at port do not offset the benefits of the economies of scale. Hence the model covers the following areas of interest: the cascade effect as a result of containership size continuous increase and the ability of the terminals to influence the arrival of new and bigger containerships, taking into account the different variables that explain the behavior of the containership size growth for the region.

Main Feedback Loops in Containership Size Growth
Let us suppose that GDP represents the economy’s growth indicator, this exogenous variable has a positive relationship with consumer demand for goods, in the destination countries where the container terminals are located, this would cause the industrial and agricultural output of neighbors and exporter nations to increase. This in turn would increase the demand for transportation (bookings) in the different transport categories. This surge in demand will in turn motivate the providers to increase freight rates in a bid to increase profitability. At the beginning this strategy will work but the basic supply and demand models have already demonstrated the demand in the medium and long term tends to be inelastic and the bookings will tend to go down if price continue to rise. This feedback loop is complemented by the relationship between the freight rates (price) and the availability of slots. When prices rise, the suppliers of transportation services tend to provide even more slots in a bid to increase revenue and profit, however in the medium term, an increase in the offer will just help decrease the price (freight rates).

Port infrastructure makes up a separate “module” with its own set of relationships even though some variables are shared. Transport demand, influenced by the factors outlined in the “Maritime Trade” has a positive relationship with number of Trips that the ships have to do. If the number of trips increases, so will the amount of containers that will need to be handled at the terminals (throughput). If the required throughput increases, Infrastructure idle capacity will decrease, increasing the market demand for more infrastructures which in turn will increase the political pressure on Port authorities and Terminal operators to invest in port infrastructure. Competitors’ available infrastructure will increase the pressure of the market (market= shipping lines, ship-owners, shippers) towards more infrastructure development to accommodate the increased throughput. Political pressure will make possible investments in new capacity which will decrease the market pressure for new infrastructure development and increase the infrastructure idle capacity. Economies of scale are influenced by the size of the containership, the more slots, less is the unit price (tonne or TEU) [21]. The economy of scale main components are costs at sea and costs at land, the later subdivided in fixed costs and operations costs. Fixed costs are influenced basically by capital costs and operation costs. The variable CostsTEU/Mile represents the Costs at sea and this variable is influenced by the daily fuel costs and distance of the journey. CostsTEU/Mile decreases below what it would have been whenever the Ship size grows and this tends to boost efforts for further increase in the ship size of the ship. At last the variable CostTEU/Port represents the costs at land, basically the time the ship spends in the terminal, this time at the terminal , represented by the variable “TimePort” is a function of the Port handling capability (PortHan) the represents ship turnover as well as container yard capacity. Below, a representation of the whole conceptual model, merging the three modules in a stocks and flows diagram is presented in figure 8, based on this diagram the simulation in Anylogic ™ will be carried out:
6. Conclusions

Two important trends currently exerting influence in the containership sizes: (1) The search for economies of scale, thus allowing big firms increase their market share at the expense of those companies unable to do so, while reaping the benefits of cargo units at reduced cost; and (2) a stagnant and weak World economy and a subsequent weak growth in the trade volumes, easily shocked by further negative developments that might provoke a worldwide double dip recession (Further collapse of European demand and/or collapse of U.S. demand, thus affecting negatively the recent engines of growth in North and South East Asia as well as other emerging markets). The main factors that drive the growth or reduction in the size of the container ships are the trade volumes at the selected routes (a function of the World Economy health), expected economies of scale, the commercial environment, the distance as well as the port productivity, infrastructure and geographic constraints. The limitations to the size of the containerships are not technical anymore, but come from the market (trade volumes, economies of scale, technical considerations of the harbors, logistic bottlenecks.) In the case of Latin America, is not expected to be severely affected by a mild economic slowdown; however the region, specifically South America, where more than 90% of all exports from Latin America to Asia originate from, is ever more reliant on the Asian demand, even though the U.S. and E.U. are still the main commercial partners. In this case, should the price for commodities fall, many of these nations can be adversely affected due to their lack of diversified exports. The growth experienced in the last years in the containership size has spurred a series of infrastructure adjustments in the terminals throughout the region, especially in the United States East Coast, México, Panamá and South America, where some terminals do this in order to stop being feeder ports and become regional hubs, and other terminals are competing in hopes to become the new hub of the region. Nowadays most of the products exported from Latin America to Asia are either raw materials or natural based products, while the exports from Asia to Latin America are mostly industrial products. The variables to use in such a model are yet to be determined, however in this project, all the possible variables suggested by the literature have been put for consideration. The study provides a conceptual model using the System Dynamics methodology which has proven very useful in diverse circumstances, where a high level of abstraction and the necessity for a deep understanding of a determined system are necessary. Possibilities for a hybrid simulation (combination of SD with one or more simulation paradigms cannot be ruled out at this time given the possibility for this course of action given by Anylogic™). Previous simulations in the maritime trade have been either static models or involved the use of discrete simulation techniques for simulation of process flows.
References